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Long-term marine litter monitoring in the remote Great Australian Bight, South Australia

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Abstract

The Anxious Bay beach litter clearance is the longest running annual survey of ocean-based litter in Australia. It's remoteness from centres of human population and location (with respect to prevailing winds and currents) make it an ideal place for monitoring ocean or ship-based litter in Australia's southern oceans and particularly, the Great Australian Bight. Over the 1991–1999 period, a large but gradual decline in the amount of beach washed litter was recorded (with minor peaks recorded during the 1992 and 1994 surveys). Beach washed litter decreased by approximately 86%, from 344 kg recorded in 1991 (13.2 kg/km) to 49 kg in 1999 (i.e. 1.9 kg/km), reaching a maximum of 390 kg in 1992 (or 15 kg/km of beach). However, a sharp increase in litter was recorded in 2000 (i.e. 252 kg or 9.7 kg/km). This increase in litter yield in 2000 is probably due to stronger than average onshore surface flow (or Ekman Transport) in the western Eyre Peninsula and Bight region. Prior to the survey in 2000, the results appeared to indicate that ocean litter on Anxious Bay beach was beginning to level out at around 50–70 kg/year (i.e. 2–3 kg/km). As the beach surveys involve the assumption that the beach is completely cleared of litter, this may represent a baseline level for ocean-based litter in the region. The yields and type of litter collected from the annual survey indicates that the majority of litter washed ashore originates from commercial fishing activities within the Great Australian Bight. Most of the fishing-related litter was directly sourced to the Southern Rock Lobster Fishery (i.e. bait buckets, baskets, pots), the Great Australian Bight Trawl Fishery (i.e. codends, trawl nets) and the Southern Shark Fishery (i.e. monofilament gillnets and longlines).

Between 1994 and 1999, large reductions were observed in the amount of bait straps (77% reduction), lobster bait baskets/buckets (86% reduction), nets/ropes (62% reduction) and floats/buoys (83% reduction). Significantly, fishing-related litter in the Bight has reduced at a slower rate than domestic litter. While the level of glass and soft plastics on the beach have both reduced by almost 93% (i.e. 103–7 kg and 119–8 kg, respectively), the level of hard plastics, has diminished at a slower rate, with reductions of only 75% (i.e. 122–30 kg). Some fisheries (i.e. rock lobster, Southern Shark Fishery) have shown marked reductions in fishing-related litter. This is probably due, to some extent, to significant reductions in fishing effort in the region, although this requires further investigation.

The information from the Anxious Bay beach litter survey is crucial in monitoring trends in ocean litter in Australia's southern oceans and compliance with international litter regulations. While fishing-related litter remains the major source of ship-based or ocean litter in Australia's southern oceans, the continued reduction in ship-based litter since 1991 supports increasing compliance to MARPOL (Annex V) by commercial fisheries and shipping in the Great Australian Bight.

While Australia participates in marine debris monitoring programs in the Antarctic (under CCAMLR), there is currently no national program or management framework to assess, manage and monitor ocean-based litter along Australia's coasts, and monitor compliance with MARPOL. Apart from the commitments under CCAMLR for Antarctic (and sub-Antarctic) marine environments, there are no other regional programs, guidelines or monitoring protocols or to assess and manage ocean litter in the Southern Ocean.

Keywords: Marine litter; Marine monitoring; Great Australian Bight; Fisheries; Fishing debris; Southern Ocean

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1. Introduction

World-wide, ship-based litter remains an increasing and persistent problem for marine ecosystems and their biota (Arnaudo, 1990; Laist, 1987; Woolfe, 1987; Ryan and Maloney, 1993). In the remote southern ocean, marine debris studies have been largely restricted to isolated, oceanic sub-Antarctic and Antarctic islands and the Antarctic Peninsula. These studies have generally focussed on the increasing impact of marine debris on wildlife, particularly seabirds and seals, and the monitoring of long-term trends in marine litter using beach debris surveys (see Gregory and Ryan, 1997). As a member of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), Australia currently undertakes regular annual monitoring of marine debris (and wildlife impacts) at Heard Island and Macquarie Island (Slip and Burton, 1992). While marine debris surveys and impact studies have been undertaken in southern temperate Australia (see Wace, 1995, for review), there is currently no coordinated, national approach to marine debris monitoring in Australian waters.

In Australia, most marine debris studies have been irregular, one-off opportunistic surveys of ocean-based marine debris (see Wace, 1995, for review) or specifically, surveys of fishing-related litter (see Jones, 1995, for review). Regular, long-term monitoring of litter is critical to ensure that Australia's Commonwealth-managed fisheries are consistent with the principles of ecologically sustainable development, in particular, the need to minimise the impact of fishing on the marine environment (Ward et al., 1998). Research in Australia over the past decade clearly indicates that fisheries litter impacts (i.e. entanglements, ingestion) and also, direct by-catch mortalities, can represent significant threats to both, marine mammals and seabirds (Pemberton et al., 1992; Gales et al., 1994; Copley, 1995; Marsh et al., 1995; Shaughnessy, 1999). As such, the disposal of plastics into the sea, including plastic fishing gear such as nets, rope, monofilament line and packaging bands used on bait boxes, is totally prohibited under Australian law (*Protection of the Sea* (*Prevention of Pollution from Ships*) *Act 1983*) which implements the International Convention for the Prevention of Pollution from Ships (MARPOL, Annex V).

The Great Australian Bight is an area of international conservation importance, containing globally significant breeding populations of rare and endangered marine mammals, and also, some of the highest levels of endemism and marine biodiversity in Australia, and the world (Edyvane, 2000). Much of this unique biota has resulted from the relatively long period of geological isolation and extensive, arid, east–west extent of the coast and also, the associated wide, open, swell-dominated continental shelf (Poore, 1995; Edyvane, 2000). The region is of national and international conservation significance for marine mammals, particularly the endangered southern right whale (*Eubalaena australis*) (Bannister et al., 1996) and the rare Australian sea lion (*Neophoca cinerea*) (Dennis and Shaughnessy, 1996; Shaughnessy, 1999), which has recently been recognised through the declaration of the Great Australian Bight Marine Park (Government of South Australia, 1998; Commonwealth of Australia, 1999).

Despite the recognised biological significance of the region, there is a risk of increasing conflicts with marine mammals and seabirds in the region from existing uses, such as commercial fisheries, and increasing activity in the region, from mammal-based tourism and new, developing commercial fisheries and sea-based aquaculture in Western Australia and South Australia (Copley, 1995; Edyvane, 2000). To this end, marine litter, particularly from commercial fishing operations within the Great Australian Bight, have been highlighted as a potential threat to marine conservation values within the region, and especially within the recently established Great Australian Bight Marine Park (Government of South Australia, 1998; Slater, 1999; Commonwealth of Australia, 1999).

The annual beach litter clearance at Anxious Bay (near Elliston, South Australia) is Australia's longest running survey of ocean or ship-based litter. A beach litter survey has been conducted annually since 1991 along this remote 26 km of ocean beach (Dalgetty and Hone, 1993; Dalgetty, 1994; Wace, 1994; Edyvane, 1998). The program utilises the scientific expertise of South Australia's marine scientists and the community involvement of schools in the rural areas of western Eyre Peninsula (i.e. Elliston and Streaky Bay region)—to raise community awareness of ship-based marine pollution and importantly, report on the status of ocean litter in Australia's vast southern ocean.

1.1. Potential sources of ocean-based litter

The current commercial use of the Great Australian Bight is largely restricted to commercial fishing (Edyvane, 2000). Recreational fishing in the region is either shore-based or limited to inshore waters. Until recently, there was no mineral or petroleum exploration or development proposals. However, in 1999, gas and petroleum acreage was released in the southern waters of the Bight (i.e. approximately 75.6 nautical miles offshore, south to the edge of the Exclusive Economic Zone) (Commonwealth of Australia, 1999).

Major offshore commercial fisheries in the eastern sector of the Bight include the State-managed Southern Rock Lobster (*Jasus edwardsii*) fishery (Northern Zone) and a number of Commonwealth-managed fisheries including the Great Australian Bight trawl fishery (based on demersal trawling), the Southern Shark fishery (using monofilament gillnets and longlines) and Australian

Table 1
Major inshore and offshore fisheries in the eastern Great Australian Bight, and Anxious Bay region

Fishery	Jurisdiction	Target species	Area of fishery	Fishery methods	Fishery trends
Northern Zone Southern Rock Lobster Fishery	SA Government	*Jasus edwardsii*	Offshore/inshore Fishing activity concentrated in the southeastern Bight, limited in central Bight due to exposure and the lack of reefal habitat	Pots	Anxious Bay (and environs) represents one of the three most significant fishing grounds for lobster in the Northern Zone Rock Lobster Fishery. Fishing effort in the region peaked in 1990–1991 and 1995–1996 and has steadily declined since
Great Australian Bight Trawl Fishery	Commonwealth	Multi-species. Continental shelf fishery (mainly deep-water flathead and Bight redfish). Seasonal slope fishery (orange roughy)	Offshore (Kangaroo Island off SA, to Cape Leeuwin, WA). Fishing activity confined to a narrow margin off the continental shelf and slope, in depths of less than 1200 m, mostly within the 100–200 m depth zone	Demersal trawling	Limited entry fishery (10 vessels). The status of shelf and slope resources is uncertain. Great Australian Bight demersal resources are unlikely to support all 10 licensed vessels fishing continuously. Fishing effort in the shelf fishery (above 250 m) increased substantially between 1994 and 1997, and then declined slightly. Annual slope (below 250 m) effort declined after an initial high in 1989 to low levels during the mid-1990s, but has gradually increased (while remaining low) from 1996 to 1999
Southern Shark Fishery	Commonwealth	Main species targeted include gummy shark, school shark, saw shark and elephant shark	Offshore. The fishery operates across the waters of several States and in Commonwealth waters, however, sharks are also taken as bycatch in other fisheries (i.e. Southeast Fishery, Great Australian Bight Trawl Fishery)	Monofilament gillnets, longlines	In the eastern Bight, the main species taken in inshore (<50 m) waters are gummy (*Mustellus antarcticus*) and bronze whaler (*Charcharinus brachyurus*) sharks, sweep (*Scorpus aquepinnis*), mulloway (*Argyrosomus hololepidotus*) and Australian salmon (*Arripis truttaceus*), and in offshore waters, school shark (*Galeorhinus galeus*), ocean leatherjackets (*Nelusetta ayraudi*) and deep sea trevalla (*Hyperoglyphe antartica*). Annual effort in the fishery increased dramatically during the 1980s and declined in the 1990s, mainly in the longline rather than the gillnet sector
Southern Bluefin Tuna	Commonwealth	*Thunnas maccoyii*	Offshore. Most fish in the Bight caught south below 32°00′S	Longline, purse-seining and pole fishery	Shift from long-ling fishing in the 1980s and early 1990s to an active purse-seining and pole fishery
Western King Prawn Fishery (West Coast)	SA Government	*Penaeus latisulcatus*	Inshore. Main fishing grounds occur in Anxious Bay, Coffin Bay and off Ceduna	Double-rigged otter trawls	Limited entry fishery (3 licences). Trawl grounds extend approximately 10 nautical miles offshore from Venus Bay and cover an area of approximately 100 square nautical miles
Marine Scalefish Fishery	SA Government	Multi-species (targeting mostly King George whiting, and also, shark, mulloway, Australian salmon)	Inshore. In the region, most fish caught in the vicinity of Anxious Bay, Waldegrave Island and Flinders Island	Large mesh gillnetting, haulnets, handlines, and rod and line	For King George whiting (*Sillaginodes punctata*), there has been a long-term decrease in handline effort, while gillnet effort has remained stable. For snapper (*Pagrus auratus*), commercial longline effort in the region has gradually decreased during the 1990s, while handline effort has increased
Pilchard Fishery	WA and SA Governments	*Sardinops neopilchardus*	Inshore. Bays to the west of the GAB (Esperance, Albany, WA) and east of the Bight (SA)	Purse-seine fishery	Annual catches in the fishery have fluctuated markedly due to mass mortality events (i.e. 1995, 1998), which affected the entire Australian population of pilchard. Total allowable catch for the SA pilchard fishery increased from 3450 tonnes in 1992–1993 to 9100 tonnes in 2001, due largely to significant increases in demand for fodder for caged tuna aquaculture, and more recently, for recreational fishing bait and human consumption

vessels fishing for Southern Bluefin Tuna (*Thunnas maccoyii*) (BRS, 1998) (see Table 1). The inshore commercial fishing activities in the eastern Bight are restricted to the lobster fishery, a Western King Prawn (*Penaeus latisulcatus*) fishery (West Coast), abalone fisheries, and a multi-species Marine Scalefish Fishery. A number of fisheries off Western Australia and in the Indian Ocean may also contribute debris to Anxious Bay.

The Anxious Bay region (including the Investigator Group), represents a significant region for lobster, abalone, prawn and marine scale fishing in South Australia. The region represents one of the three most productive fishing grounds in the Northern Zone Rock Lobster fishery (Edyvane, 1999; Ward et al., 2002) and produces approximately 80% of the West Coast Prawn Fishery catch for South Australia (Wallner, 1985; Boxshall, 2001). Larval *P. latisulcatus* migrate from the offshore spawning areas in Anxious Bay to the primary nursery area at Venus Bay (Wallner, 1985). Similarly, the Anxious Bay region is also a major fishing ground for species caught within the Marine Scalefish Fishery, with King George whiting (*Sillaginodes punctata*) being the major species targeted by fishers (by handlines). While the region is a major fishing ground for commercial abalone (Edyvane, 1999; Keesing et al., 2000), as a diver-based fishery, it is unlikely to contribute significantly to fishing debris.

Offshore fisheries are another (albeit remote) source of potential litter at Anxious Bay. The Southern Shark Fishery has operated for more than 60 years in the region, targeting several temperate species of shark, and other species of marine scalefish. However, the majority of this catch (90%+) is made up of shark (see Table 1). Large mesh gill netting (>15 cm mesh) is by far the most important method of capture, followed by handlines and rod and line (Jones, 1991). Further offshore, the Great Australian Bight Trawl Fishery extends from Kangaroo Island off South Australia, to Cape Leeuwin in Western Australia, a distance of over 2000 km. The fishery consists of a continental shelf fishery (targeting mainly deepwater flathead and Bight redfish), and a seasonal slope fishery (targeting orange roughy). However, fishing activity is limited (i.e. 10 vessels) and is confined to a fairly narrow margin off the continental shelf and slope, in depths of less than 1200 m, mostly within the 100–200 m depth zone (BRR, 1993, 1994). Similarly, in the tuna fishery, in recent years, there has been a shift away from longline fishery to a purse seine, pole and troll fishery, with most young fish (1–4 years) in this Australian fishery now taken in relatively shallow waters associated with coasts and continental shelves, south below 32°00′S and east of the Great Australian Bight (Jones, 1991; BRR, 1995).

1.2. Physical setting

The Great Australian Bight forms part of the southern shelf of Australia, which is the northern boundary of the South Australian Basin of the South East Indian Ocean. The inshore regions of the Bight extend over 1200 km, from Cape Pasley (near Esperance), in Western Australia to Cape Catastrophe, at the entrance of Spencer Gulf in South Australia (ACIUCN, 1986) (see Fig. 1). Along this highly variable coastline there are spectacular cliffs and rocky headlands, numerous offshore islands, surf-pounded beaches and large sheltered embayments (Short et al., 1986). The coast from Cape Leeuwin to Tasmania is the longest stretch of east–west, ice-free coastline in the Southern Hemisphere and is characterised by high deepwater wave energies, with no true rivers or streams arriving at the coast (Short et al., 1986; Edyvane, 1998). As such, there are no true estuarine environments along the coast and the extensive shallow swell-dominated shelf, is characterised by a lack of any significant fluvial input.

The climate of the Great Australian Bight is largely influenced by mid-latitude anticyclones or high pressure systems which pass from west to east along the continental coast (Bye, in press). Coastal processes are dominated by a persistently high southwest swell, generated by these westerly moving low pressure cyclones south of the mainland (Bye, in press). Winter generally brings southerly to southeasterly winds and low pressure systems which travel across the Southern Ocean between 40° and 50°S, bringing frontal activity and rain. Summer brings northerly to northwesterly winds. Along the Great Australian Bight and the western coast of Eyre Peninsula, strong wave action and westerly, onshore winds have reworked the coast, resulting in undercut cliffs and some extensive dune development. Adjacent to the only circumpolar ocean (the Antarctic circumpolar current), the swell-dominated coast of the Great

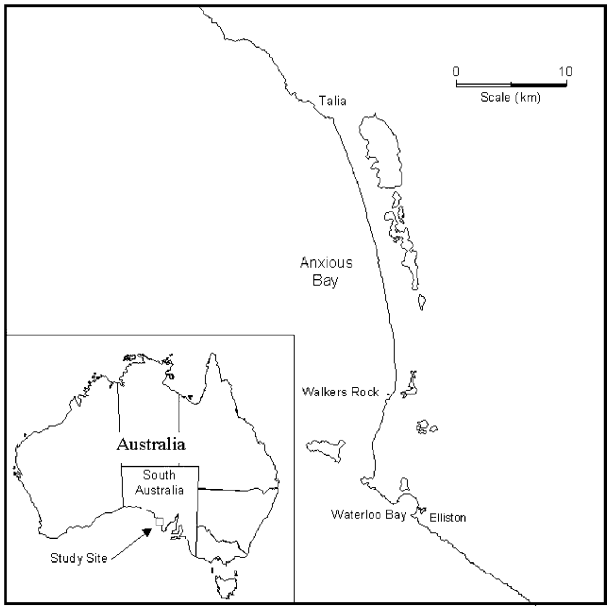

Fig. 1. Map of sampling sites.

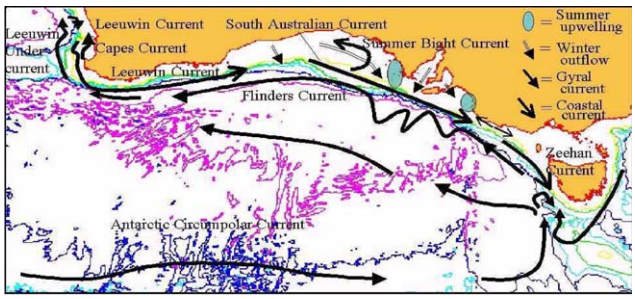

Fig. 2. Major currents and oceanographic processes of the Great Australian Bight region (from Bye, in press). [This figure can also be found as Fig. 6 at: http://www.es.flinders.edu.au/~pbarker/bye.html.]

Australian Bight experiences some of the world's highest and most persistent waves (Chelton et al., 1981).

Oceanographically, the Great Australian Bight represents the northern part of the southeast Indian Ocean. Circulation within the Bight is dominated by a wind-driven anti-cyclonic gyre with strong upwelling in the east (Herzfeld and Tomczak, 1997; Herzfeld et al., 1998). The southern limit of this circulation (and the northern boundary of the Southern Ocean) is the Subtropical Front, or the northern boundary of the Southern Ocean that lies at 39–40°S south of the Bight, but closer to 47°S in the vicinity of Tasmania. Four major water masses or currents influence the oceanography of the Great Australian Bight (and Anxious Bay) region (see Fig. 2):

(i) the Leeuwin Current, a poleward eastern boundary current which flows along the continental shelf edge of Western Australia and brings warm, nutrient poor equatorial waters of low salinity (35.0%) from the tropical waters of the Indian Ocean to the southern parts of Western Australia and the Great Australian Bight (Rochford, 1986; Cresswell, 1991; Herzfeld, 1997; Herzfeld and Tomczak, 1997);
(ii) the central Bight water mass from the southeast Indian Ocean, which occurs in the central and eastern half of the Great Australian Bight for most of the year, and drifts to the southeast and occupies much of the shelf and slope region east of 135°E, particularly in winter (Rochford, 1986);
(iii) the West Wind Drift cold water mass, which is found throughout the year off the slope region of southern Australia and periodically intrudes into the shelf break, especially when the Leeuwin Current is weakly developed (Rochford, 1986); and
(iv) and the surface-flowing Flinders Current, which originates from the gyre south of South Australia (Bye, 1972).

The Great Australian Bight region is one of the most sparsely inhabited regions of southern temperate Australia (Edyvane, 2000). This is due largely to the arid landscape and its limited potential for grazing and agriculture. The closest and largest coastal townships in the region include Ceduna (population 2877) and Streaky Bay (population 992) to the east, and Eucla (population <500) to the west. A large proportion of the coastal land in the region is reserved in coastal national parks and conservation reserves (Edyvane, 2000). This includes Cape Arid National Park (279,832 ha) and Cape Le Grand National Park in the western Bight, to the Nullarbor National Park (588,300 ha) and Wahgunyah Conservation Reserve (15,555 ha) in the central Bight region together with several other smaller conservation reserves and parks. In the eastern Bight, several large national parks, such as the Coffin Bay National Park (28,106 ha) and Lincoln National Park (29,060 ha) reserve significant areas of pristine coastal wilderness.

Prevailing winds, currents and relative isolation, make Anxious Bay an ideal place for monitoring ocean or ship-based litter in Australia's southern oceans and particularly, the Great Australian Bight (Wace, 1994). The beach is far away from any centres of human population and is a natural trap for flotsam arriving with the westerly winds and carried by the Antarctic circumpolar current (or West Wind Drift), which brings debris from a large area of the Indian and South Atlantic oceans between South America and Australia. As such, the oceanographic processes, the eastward advection and transport, and the westward facing coastline of the western Eyre Peninsula (where Anxious Bay is located) result in Anxious Bay being a natural trap for litter discarded and lost overboard in the southern ocean. The extensive beach is also relatively free of large amounts of beach cast seaweed that smothers and conceals other beach debris. Located within the Lake Newland Conservation Park, the beach has limited vehicular access, but there is some limited 4WD activity.

2. Methods

2.1. Study site

Anxious Bay (near Elliston, population 209) is located in the eastern Great Australian Bight, on South Australia's western Eyre Peninsula (Fig. 1). Anxious Bay is an isolated, westerly facing 26 km beach, continuous Holocene dune barrier system, bounded at either end by extensive dune calcarenite cliffs, and backed by a 20 km long saline lake (Lake Newland), which occupies the back barrier depression (Edyvane, 1998). It is a high-energy sandy beach with few rock outcrops and no shingle or large shells. The sand is >90% calcareous. Calcarenite rocks and offshore reefs, and Holocene beach and dune sands are the principal source of beach sediments (Short et al., 1986).

2.2. Beach litter survey methods

The annual survey involves the systematic clearance of all litter from the 26 km beach, fore dunes and the frontal edge of the main dunes—and importantly, the sourcing of all litter into litter types and also, the origin of the litter. Litter was collected and removed for each 1 km section of beach, fore dunes and main dunes. Individual items of 'megalitter' (i.e. greater than 2 cm across) were cleared of sand, classified, counted and weighed. The collected litter was classified as either hard (i.e. moulded) plastic, soft plastic (i.e. flexible and foamed), glass, metal or rubber. However, no metal was recorded in the 1991 survey. Driftwood was not included in the survey, although large baulks of timber have been seen on the beach each year. If possible, the origin of the litter was also determined. Fishing related litter was identified and sourced by local volunteer fishermen. Individual items of fishing-related debris (i.e. bait pots/baskets, lobster pot collars, rope/nets, floats/buoys, bait straps) were not weighed or counted in the 1991 and 1992 surveys.

Items of biogeographic interest (i.e. long distance or 'exotic' litter, oceanographic drift cards, etc.) and also, natural marine flotsam was also recorded. This included many derelict wedge-tailed shearwaters, tagged wildlife (i.e. tuna, albatrosses) and also stranded sealife. Pumice, marine bitumens and resins were only recorded in 1991, 1992, 1996 and 1999 surveys. The annual ocean litter survey was generally conducted over 3 days (followed by 1–2 days of sorting), generally during spring (see Table 2 for dates).

2.3. Longshore drift and drift card studies

In addition to the annual beach clearance of litter, we also sought to determine the prevailing pattern of local inshore water movement and any longshore drift along Anxious Bay beach In 1993, 25 round plastic (i.e. polypropylene/polyethylene markers) or 'trilobites' (i.e. foaming device found in cans of alcohol), were deposited at low water on the beach, at 5 km intervals. In the 1994 survey, 50 plastic oceanographic drift cards (blue, green) were released at low water at the 5, 10, 15 and 20 km mark along Anxious Bay beach (see Table 7).

Oceanographic drift card studies, investigating broadscale water movement patterns in the Great Australian Bight were conducted by the former South Australian Department of Fisheries (Dr Peter Petrusevics, marine consultant, personal communication).

3. Results

The yields from 10 years of beach clearance at Anxious Bay are summarised in Tables 2–5 and Figs. 3 and 4. Overall, beach washed litter declined by 27% between 1991 and 2000, from 344 kg in 1991 to 252 kg in 2000 (Fig. 3). However, a larger but gradual decline in litter was recorded over the 1991–1999 period (with minor peaks recorded during the 1992 and 1994 surveys), with the level of ocean litter on the Anxious Bay beach reducing by approximately 86%, from 344 kg recorded in 1991 (13.2 kg/km) to 49 kg in 1999 (i.e. 1.9 kg/km) (see Table 2). The maximum rate of change was −88%, from a maximum of 390 kg (or 15 kg/km of beach) of litter recorded in 1992, to a minimum of 49 kg in 1999. A sharp increase in litter was recorded in 2000 (i.e. 252 kg or 9.7 kg/km). Prior to 2000, the results appeared to indicate that ocean litter on Anxious Bay beach is beginning to level out at around 50–70 kg/year (i.e. 2–3 kg/km). As the beach surveys involve the complete removal of litter, this may represent a baseline level for ocean-based litter in the region.

Table 2
Weights and categories (and relative proportion) of ocean-based litter as recorded from the annual Anxious Bay beach litter surveys, 1991–2000

Date of survey	Glass	% Total	Soft plastic	% Total	Hard plastic	% Total	Metal	% Total	Total litter (kg)	Litter (kg/km)
1–14 October 1991	103	30	119	34.5	122	35.5	NR	NR	344	13.2
9–15 October 1992	123	31.3	127	32.3	121	31.5	20.5	4.9	391	15.0
10–14 October 1993	49	22.7	64	29.6	56	25.9	47	21.8	216	8.3
18–21 September 1994	116	37.6	89.2	28.9	81.6	26.5	21.5	7	308.3	11.8
September 1995	26	17	57.5	38	64.8	43	2.5	2	150.7	5.8
25–27 October 1996	21.7	19.3	84	19.5	62.3	55.2	6.8	6	174.8	6.7
21–23 September 1997	12.5	9.9	59.5	47.4	46.3	36.8	7.3	5.8	125.5	4.8
12–15 October 1998	12.6	17.8	6.9	9.7	45.7	64.3	5.9	8.3	71.1	2.7
21–24 September 1999	7.2	14.9	8.4	17.4	30.7	63.1	2.3	4.6	48.6	1.9
13–14 September 2000	27.7	11.0	77.2	30.6	99.7	39.5	47.8	19.0	252.4	9.7
% Change 1991–2000	−73.1		−35.1		−18.3		+233.2[a]		−26.6	−26.5
% Maximum change	−94.1		−94.6		−74.8		−95.1		−87.6	−87.3

NR = not recorded.
[a] 1992–2000 comparison.

Table 3
Major categories of beached marine litter in the Great Australian Bight recorded from the annual Anxious Bay ocean litter surveys, 1991–2000

Type of litter	Common litter	Activity
Hard plastic (moulded)	Liquid containers (bottles, tops, fragments)	General
	Drums, buckets, crates, boxes	General
	Bait/burley baskets, lobster pot necks	Fishing-related
	Buoys, floats	Fishing-related
Soft plastic	Bags and polythene sheeting	General
	Rope	General
	Nets, cod-ends, fishing line, bait straps	Fishing-related
	Buoys and floats	Fishing/general
	Six pack holders, polystyrene, rubber	General
Glass	Bottles, jars	General
	Light globes, fluorescent tubes	General
Metal	Cans (food and drink), aerosol cans	General
	Drums (oil containers)	General
	Floats and buoys	Fishing/general

Table 4
General trends in fishing debris in the Anxious Bay ocean litter survey, 1994–1999

Type of fishing debris	1994 Survey	1999 Survey	% Decrease (1994–1999)
Bait baskets/buckets	120 (7.25 kg)	17	85.8
Bait straps	376 (24 uncut)	87 (2 uncut)	76.9 (91.7)
Nets/ropes	61 kg	23 kg	62.3
Lobster pot collars	2	2	0
Floats/buoys	36	6	83.3

Table 5
Trends in items of marine debris in the Anxious Bay ocean litter survey, 1991–2000.

Litter item	Year of survey									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Glass bottles	191	238	85	172	48	55	22	24	27	49
Glass jars		31	12	28	14	6	1	4	5	9
Light globes/tubes	47	21/20	32	73	18	11	2	0	1	26
Cans (drink, aerosol)	Many	69	38	21	55	31	35	30	12	50
Bait pots/baskets	NR	>50	45	120	15	40	24	24	17	37
Lobster pot collars	NR	NR	2	2	0	1	1	3	2	0
Rope/nets (kg)	NR	Very abundant	36.2	61	48.5	47.5	42.8	16	22.75	78.6
Bait straps (uncut straps)	NR	Abundant (43)	1.105 kg[a] (27)	376 (24)	171 (8)	208 (6)	40[b]	27 (24)	87 (2)	289 (4)
Floats/buoys	NR	Numerous	27	36	8	17	7	9	6	15

NR = not recorded.
[a] Cut bait straps were weighed in 1993 (and uncut straps were counted).
[b] Cut versus uncut bait straps was not recorded in 1995.

The yields and type of litter collected from the annual survey indicates that the majority of litter washed ashore originates from commercial fishing activities within the Great Australian Bight (see Table 3). Most of the fishing-related litter was directly sourced to the Southern Rock Lobster Fishery (i.e. bait buckets, baskets, pots), the Great Australian Bight Trawl Fishery (i.e. codends, trawl nets) and the Southern Shark Fishery (i.e. monofilament gillnets and longlines).

In 1994, litter directly associated with commercial fishing activity (i.e. bait box strapping tapes, buoys, ropes, nets, bait buckets, baskets, pots) accounted for 91 kg of litter (or 30% of the total litter collected). Non-sourced litter included toilet cleaners, detergent bottles and food containers. In 1998, fishing debris accounted for approximately 25 kg (or 35% of the total litter).

Where fishing-related litter could be sourced to specific fisheries, it is clear that some fisheries (i.e. rock

lobster, Southern Shark Fishery) have shown marked reductions in fishing-related litter. Significantly, between 1994 and 1999, large reductions have been observed in the amount of bait straps (from 376 to 87, i.e. 77% reduction), lobster bait baskets/buckets (from 120 to 17, i.e. 86% reduction), nets/ropes (from 61 to 23 kg, i.e. 62% reduction) and floats/buoys (from 36 to 6, i.e. 83%) (see Table 4). The number of uncut bait straps reduced by 92% (i.e. 24–2). A large trawl net was found in 1994, accounting for the high level of rope/nets recorded in this year (i.e. 61 kg). In 1995, a large mesh monofilament net (weighing 6 kg) was also recorded. In 2000 (and to a lesser extent, 1999), significant increases in fishing-related debris were recorded for bait straps (289), ropes/nets (77 kg) and floats/buoys (15) (Table 5).

These reductions in fishing-related litter can also be correlated, to some extent, with reductions with fishing effort in some inshore fisheries. As such, fishing effort has reduced significantly in the Anxious Bay region (Fishing Zone 15), particularly post-1996 (see Table 1). For instance, overall effort in the Southern Shark Fishery has declined significantly over the 1990s (in both, the gillnet and longline sector) (BRS, 2002). In contrast, fishing effort in the shelf fishery (above 250 m) in the Great Australian Bight Trawl Fishery increased substantially between 1994 and 1997, and then declined slightly (BRS, 2002).

Significantly, fishing-related litter in the Bight between 1991 and 1999 has reduced at a slower rate than domestic litter. While the level of glass and soft plastics on the beach have both reduced by almost 93% (i.e. 103–7 kg and 119–8 kg, respectively), the level of hard plastics, has diminished at a slower rate, with reductions of only 75% (i.e. 122–30 kg) (see Fig. 3). This is reflected in the increasing proportion of hard plastics (dominated by fishing-related debris) in the total amount of litter collected (see Fig. 4), which increased from approximately 35% in 1991, to approximately 65% of the total litter collected in 1998 and 1999 (Table 2). While sharp increases were recorded for all litter categories in 2000, there was still an overall reduction in litter for most litter categories between 1991 and 2000, with glass reducing by 73%, soft plastic 35%, and hard plastic 18%. Metal was the only litter category that increased (233%) over the 1991–2000 period. Significantly, the proportion of fishing-related litter continued to increase in the 2000 survey. This is reflected in the continued decrease in glass (i.e. 11%), and the increase in soft plastics (31%), which comprised mostly ropes, nets and large buoys (Table 2).

Since 1991, glass litter has reduced by almost 93%, and comprised mainly bottles, jars, light globes and fluorescent tubes (Table 3). The number of light globes and fluorescent tubes reduced from 47 in 1991 to none recorded in 1998 (reaching a maximum of 73 in 1994) (Table 5). Of the 116 kg of glass collected in 1994, 124 alcohol bottles were collected—the most favourite being

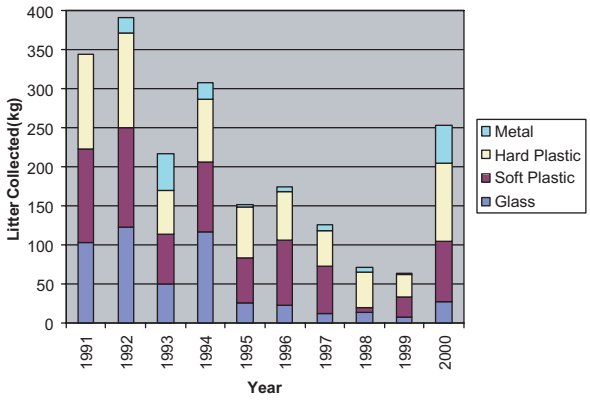

Fig. 3. Weights of ocean-based litter as recorded from the annual Anxious Bay beach litter surveys, 1991–2000.

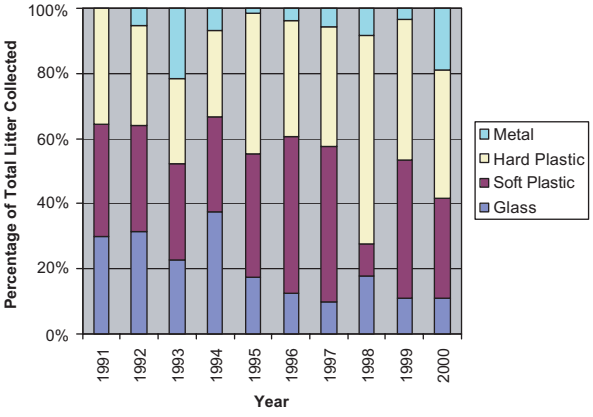

Fig. 4. Changes in the proportion of ocean-based litter by weight as recorded from the annual Anxious Bay beach litter surveys, 1991–2000.

whisky (40 bottles). While *Johnny Walker* and *White Horse* appeared popular choices, 8 bottles of *Suntori* Japanese whisky were also, collected—presumably from the Japanese longline fishing vessels in the Australian Fishing Zone. However, while it may appear that scotch is the most favourite drink among seafarers in the Great Australian Bight, beer drinking may in fact be more prevalent because beer bottles tend to be generally unstoppered—and hence, sink. Anxious Bay beach is a good site for monitoring stranded ocean litter because it is inaccessible to all but the most determined walkers, and unattractive to campers and other beach visitors who leave litter (especially bottles) behind.

The greatest amount of ship-based litter was found in the northern sections of the beach (20–26 km), the least amount in the central section (5–20 km). Glass (i.e. bottles, jars, fluorescent tubes, globes) was most often found in the back dunes. Plastics tended to be found on the beach. Aluminium cans were most prevalent in the northern section of the beach (>20 km) and probably reflect shore-based litter from recreational campers.

A problem with interpreting the yields of litter from the beach arises from beach visitors, especially at the northern end of the beach, and increasingly from the incursion of four wheel drive vehicles whose passengers may leave litter all along the beach, or even collect attractive items and so distort the annual yields.

In recent years, there has been an increase in camping litter, particularly aluminium cans and stubbies, near northern end of the beach. This is probably due to increased access by 4WD vehicles and campers.

While beach litter on Anxious Bay originates predominantly from fishing and shipping activities in the Bight waters—exotic items and long-distance litter have also been recorded (see Table 6). These include: a 'message in a bottle' from Cape Town (South Africa); a milk bottle crate from Durban, and a 'Pepsi' bottle (South Africa); a Chinese life vest; mixed 'Congee' (Taiwan); detergent bottles (Greek, Japanese, South America); toilet cleaners and body sprays (Dutch); mineral water bottle (South America); and general domestic cleaning fluids with inscriptions in Asian languages (e.g. Korean, Indonesian). Items with such inscriptions are not sold in Australia, and are presumably jettisoned from foreign vessels at sea.

Natural flotsam was also recorded during the beach survey, cuttlebones were the most abundant item, but were not counted. Wildlife strandings included a stranded dead tropical turtle; a dead Australian sea lion (*N. cinerea*), and also, a tagged albatross (Tag Number 127, white darvic band); derelict short-tailed shearwaters (*Puffinus tenuirostris*), dessicated seahorses, and a tagged Southern Bluefin Tuna (*T. maccoyii*) (see Table 6). There are two possible options for the identity of the tagged albatross: (1) a wandering albatross (*Diomedea exulans exulans*) banded on Crozet Island in the sub-Antarctic in 1972 (this bird has not been visiting Crozet since 1990), and (2) an Amsterdam albatross, banded on Amsterdam in 1983 (this bird was last controller on Amsterdam in April 1996) (Henri Weimerskirch, Centre National de la Recherche Scientifique, France, personal communication). All tagged birds have a metal band on the other leg, however this was not recorded during the survey. There was no evidence of litter entanglements with any of the dead stranded wildlife. Pumice, marine bitumens from seabed seeps and resins from Indonesian rainforest trees have also been recorded.

Oceanographic drift cards were also recorded in the study (see Table 7). A total of 6 oceanographic drift cards from the Great Australian Bight Drift Card Study were retrieved. Cards labelled GAB 5550 and 7300 were not released in the GAB (Peter Petrusevics personal communication). Information on the release locations for drift cards GAB 1000, 1120 and 1750 was not available. In addition, a total of 5 inshore 'drift cards' and 1 'trilobite' were retrieved in the two inshore longshore drift studies. Four of the inshore 'drift cards' were retrieved one year after being deposited on the beach (in 1994), in the near and far dunes. One 'trilobite' was recovered in 1994. Although the inshore cards and the 'trilobite' showed no evidence of longshore movement along the beach, the majority of items were recorded in the northern section of the beach. This suggests a stronger depositional environment and correlates with the pattern of litter deposition along the beach. The failure to find other 'trilobites' on other surveys was most likely the result of them being misclassified as miscellaneous plastic litter, rather than 'drift cards'.

Table 6
Items of foreign litter and natural flotsam in the Anxious Bay ocean litter survey, 1991–2000

Year of survey	Items of foreign litter	Natural flotsam, strandings
1991	South African milk crate and drift card, Uruguayan and Argentinian liqueur bottles	Many cuttlebones; derelict shearwaters; few seahorses; pumice
1992	'Suntori' whiskey bottles (Japan)	Many cuttlebones; few prions; few dolphins; few seahorses; many moths; pumice
1993	'Coke' bottle (Spain); distilled water bottle (Kuwait)	Not recorded
1994	'Suntori' whiskey bottles (Japan); 'Pepsi' soft drink bottle (South Africa), 'Raucauti'; a life vest (China); mixed 'Congee' (Taiwan); detergent bottles (Greek, Japan, South America); toilet cleaners and 'Impulse' body spray (Dutch); mineral water bottle (South America); jar, bowl (China); plastic bottle (German); Royal Navy plastic	Many seabirds; Porcupine fish
1995	Message in a bottle (from Cape Town, South Africa); tube of sealant (Japan)	Not recorded
1996	'Suntori' whiskey bottles (Japan); plastic containers (Japan, Singapore); detergent bottle (Singapore); bottle (Italy); shampoo bottles (Japan, Hamburg); dishwashing liquid bottle (Japan); bottle of tuna oil (USA)	Tropical turtle; Australian Sea Lion; tagged Albatross (no. 127); tagged Southern Bluefin Tuna. Resin block (350 g)
1997	None recorded	Not recorded
1998	Two plastic bottles (Asia)	Not recorded
1999	One plastic saki cup (Asia)	Pumice
2000	None recorded	None recorded

Table 7
Plastic markers, drift cards, and tagged seabirds found on the beach in the Anxious Bay ocean litter survey, 1991–2000

Research program	Items recorded	Comments
Great Australian Bight Drift Card Study (Dr Peter Petrusevics, South Australian Department of Fisheries)	GAB (17–18 km, far dunes, 1996); GAB 5550, 1000, 1750, 7300 (20–21 km, beach, 1996); GAB 1120 (21–22 km, near dunes, 1996)	Cards labelled GAB 5550 and 7300 were not released in the GAB (Peter Petrusevics, personal communication). Information on release locations for drift cards GAB 1000, 1120 and 1750 was not available
Anxious Bay Plastics Degradation Study (Professor Nigel Wace, Australian National University) (released October 1993)	1 polypropyline marker ('Trilobite') recovered (25 km, 1994). Sand-blasted but not crazed or cracked	Single recovery after only one year on beach. No longshore movement along beach
Anxious Bay Longshore Drift Card Study (Dr Karen Edyvane, South Australian Research and Development Institute) (released October 1994)	Green LHS (4–5 km, beach, 1995); Blue LHS (14–15 km, near dunes, 1995); Blue LHS (15–16 km, far dunes, 1995); Blue RHS (19.5 km, far dunes, 1995); Blue RHS (19–20 km, near dunes, 1996)	Four recoveries after only one year on beach. One recovery after 2 years on beach. All cards showed no longshore movement along beach
Albatross Tagging Program	Tag No. 127 (white darvic band)	There are two possible options for the identity of the tagged albatross: (1) wandering albatross (*Diomedea exulans exulans*) banded on Crozet Island in 1972, and (2) an Amsterdam albatross, banded on Amsterdam in 1983 (Henri Weimerskirch, Centre National de la Recherche Scientifique, France, personal communication)

4. Discussion

Ocean or ship-based litter remains a persistent global problem for marine ecosystems and their biota, even in remote ecosystems such as the Southern Ocean. High concentrations of floating debris are generally found near shipping lanes, around fishing areas and in oceanic convergence zones (Pruter, 1987). In uninhabited and highly isolated regions, such as the Antarctic and sub-Antarctic, where shipping traffic is relatively light, there is increasing evidence of the impact of debris on marine life, particularly seals and seabirds (Arnould and Croxall, 1995; Bonner and McCann, 1982; Eriksson and Burton, 2001a,b; Slip et al., 1990; Walker et al., 1997). In southern Australia, the beach litter survey at Anxious Bay (Dalgetty and Hone, 1993; Dalgetty, 1994; Wace, 1994; Edyvane, 1998) remains the only long-term annual ocean debris (i.e. ship-based) survey in Australia (Wace, 1995).

While irregular, opportunistic surveys have been conducted in Tasmania (Slater, 1991, 1992) and Victoria (Heislers, 1994), quantitative comparisons with Anxious Bay are difficult because of differing sampling methodologies. Despite this, it is clear that fishing-related litter remains the major source of ship-based or ocean litter at Anxious Bay and in Australia's southern oceans. Further, the levels of marine debris recorded at Anxious Bay are low, reflecting the low level of inshore and offshore fishing and shipping activity (and distance from major shipping routes). In eastern Victoria (where the continental shelf break is significantly closer), inaccessible beaches at Cape Liptrap were heavily littered in September 1992 with plastic fishing gear and wastes from foreign vessels (Heislers, 1994). Similarly, in Western Australia, a survey of a one-kilometre beach at Eyre Bird Observatory in 1990–1991 resulted in 494 items, the majority of which was fishing gear. The litter consisted of 5% glass, 47% moulded plastic, 41% flexible plastic (12% of which was rope), 4% metal and 3% wood (Wace, 1995). In 1990 and 1991, Slater (1991) recorded 50,111 items (i.e. 300–350 items/km), mostly fisheries-related debris, in 150 surveys undertaken on 88 beaches on the remote coast of southwest Tasmania. Most of the debris (61%) was ocean-sourced plastic, of which 80% was plastic fishing debris from offshore fisheries (Slater, 1992). This level of marine debris is much higher than recorded levels at Anxious Bay and clearly underscores the relatively high level of fishing activity and commercial shipping off southwestern Tasmania.

In contrast, debris levels along Anxious Bay more closely approximate levels recorded on isolated and remote sub-Antarctic islands, such as Heard Island (317 items, or 13 items/km) and Macquarie Island (182 items, or 9.1 items/km) (Slip and Burton, 1990). The higher densities of marine debris (and fishing debris) at Heard Island (located south of the Antarctic Polar Front) compared with Macquarie Island (located just north of the Antarctic Convergence), results from the presence of a commercial fishery on the Kerguelen Plateau, which operates to within 200 nautical miles of Heard Island (Slip and Burton, 1990). At the broader scale, levels of marine debris above the Antarctic Convergence (north of 50–60°S), are generally higher (i.e. 76–4120 items/km) than below the Antarctic Convergence (including the oceanic islands in the Scotia Arc, such as South Georgia, South Sandwich Is., South Orkney Is. and South

Shetland Is.) (i.e. 0–1291 items/km) (Gregory and Ryan, 1997; Convey et al., 2002). This is because the Antarctic Circumpolar Current acts as an effective oceanographic barrier to floating debris from the Atlantic, Indian and Pacific oceans entering the Antarctic marine environment.

4.1. Trends in marine litter

Over the past decade (between 1991 and 2000) there has been a significant reduction in ocean or ship-based litter at Anxious Bay. Since November 1990, international shipping regulations (i.e. MARPOL, Annex V) have prohibited the dumping of rubbish at sea by all ships (including recreational craft). Information from the Anxious Bay beach litter survey is crucial in monitoring trends in ocean litter in Australia's southern oceans and compliance with this international regulation. Overall, beach washed litter declined by 27% between 1991 and 2000, with a maximum decrease of 88% between 1992 and 1999. In this regard, the continued reduction in ship-based litter since 1991 supports increasing compliance to MARPOL by marine industries and shipping in the Great Australian Bight region. Excluding the results for the survey conducted in 2000, the results appear to indicate that beach washed ocean litter on Anxious Bay beach is beginning to level out at around 50–70 kg/year (i.e. 2–3 kg/km). As the beach surveys involve the complete removal of litter, this may represent the baseline level for ocean-based litter in the region. However, only future surveys will more accurately define this baseline.

In the sub-Antarctic, long-term marine debris monitoring programs clearly indicate increasing levels of marine debris, and associated impacts on marine wildlife (entanglements, ingestion). At Macquarie Island, beach surveys recorded a total of 1035 'macroplastics' items (or 27.6 items/km) in 2001 (Eriksson and Burton, 2001b), compared to 621 items (or 6.6 items/km) recorded in 1988 (Slip and Burton, 1990). Similarly, monitoring at Bird Island (South Georgia) from 1990–1995 reported a significant increase in marine debris (i.e. 9–725 items), particularly in 1995, which coincided with increased longline fishing in the area (Walker et al., 1997). Significantly, the increase in incidence of synthetic line (as used in longlines) found ashore corresponded to an increase in the proportion of Antarctic fur seal *Arctocephalus gazella*, entanglements in a parallel study (Arnould and Croxall, 1995).

The sharp, and unexpected, increase in beach washed litter in the 2000 survey at Anxious Bay, reinforces the need for continued long-term litter monitoring and also, the need for complementary information on local and regional oceanography and weather conditions. In this regard, inspection of the oceanographic records for the Great Australian Bight for 1991–2000 reveals a stronger than average onshore local surface flow (or Ekman Transport), driven by local winds blowing on the surface of the ocean, in the western Bight in September 2000 (Duncan Tippins, Flinders University of South Australia, personal communication). Unlike 'dynamical' currents, like the Leeuwin, Zeehan and Flinders Currents, which are driven by large-scale ocean pressure gradients, this local surface flow could very easily affect the local surface currents in the region. The local average September wind regime for the west coast of Eyre Peninsula is weak northwesterlies, resulting in weak onshore surface transport. However, in September 2000, they were relatively strong west–northwest. This would result in Ekman Transport that is to the north–northeast in the open ocean, northeast over the deeper shelf and the same as the wind within 20 km of the coast. This strong onshore surface transport could very well explain the large increase in litter in the 2000 survey.

Recent underwater surveys of the seafloor of the European coast (Galgani et al., 1996, 2000) and Southern California Bight (Moore and Allen, 2000), indicate that marine debris can accumulate on continental shelves and slopes, or occur as large floating plastic 'rafts', as reported in the Gulf of Mexico (Lecke-Mitchell and Mullin, 1997). Local inshore current patterns and poorly known in the Anxious Bay region, as are the retention times for marine flotsam and litter. As such, large amounts of litter may have been retained and/or accumulated at sea, and released under the favourable oceanographic conditions in 2000. While there are no anecdotal reports of large amounts of floating litter in the region, further study, including debris surveys of the seafloor, are clearly required.

Studies on the beach-dune dynamics at Anxious Bay would also clearly assist in interpreting the spatial and temporal pattern of marine debris accumulation and composition. As such, types of litter behave differently on different sections of the beach, particularly in respect to coastal processes. Recent studies in New Jersey (Thornton and Jackson, 1998) have shown that the cross shore spatial distribution of debris reflects the influence of wind or wave processes across the profile with small lightweight debris on the wind-dominated upper profile and heavier debris on the wave-dominated lower profile. More plastic was observed than expected in the dune and back beach areas with the greatest quantities found after onshore winds. More glass was observed than expected on the foreshore where low wave energies prevent transport higher on the beach profile. This pattern of debris accumulation and composition was also observed at Anxious Bay.

4.2. Fisheries litter

Results from the annual surveys conducted at Anxious Bay indicate that commercial fisheries are a

major contributor to ocean litter in the Bight (Wace, 1994; Edyvane, 1998). As such, much of the marine litter can be sourced directly to trawling, lobster and commercial netting operations presently conducted within the Great Australian Bight (i.e. lobster pots and bait baskets, cod-end nets from trawl fisheries, gillnets, bait packaging straps, plastic ropes and floats). Some litter is fisheries-specific, such as lobster pots and bait baskets, and monofilament nets that can be sourced directly to recreational and commercial gillnet fisheries, and the Southern Shark Fishery. Other litter however is fishing-related, but cannot be directly sourced to a specific fishery. For instance, bait box packaging bands are used in the South Australian and Western Australian lobster fisheries, Southern Shark Fishery and possibly, Japanese longline vessels. Fishing-related litter (i.e. hard and soft plastics) in the Bight has reduced at a slower rate than domestic litter. As such, MARPOL appears to have been more effective in reducing domestic and shipping-related litter.

The reduction in fishing-related litter in the Great Australian Bight could be due to increased awareness of the MARPOL Annex V and also, reductions in fishing effort. Specific fisheries in the Great Australian Bight, such as the rock lobster fishery and Southern Shark Fishery, are associated with significant reductions in fishing-related litter at Anxious Bay, as evidenced by the reductions in lobster bait pots/baskets and monofilament nets. In contrast, in Marmion Marine Park (Western Australia), litter from the State-managed rock lobster industry increased from 32% in 1985 (Cary et al., 1987) to 41% of the total weight of litter in 1992 (Edwards et al., 1992). The main debris items from the rock lobster fishery there were rope, plastic bait wrapping and plastic packing bands from bait boxes.

Reductions in fishing-based litter may also be the result of changes or reductions in fishing effort in the Bight. Fishing effort has reduced in several major inshore fisheries in the eastern Great Australian Bight during the 1990s. At a fishery level, there has been significant reductions in effort in both, the longline, and to a lesser extent, the gillnet sector of the Southern Shark Fishery (BRS, 2002). Similarly, in the Anxious Bay region (Fishing Zone 15), there has been a significant reduction in effort in lobster fishing (post 1996), which correlates with a reduction in fisheries-specific litter (i.e. bait pots/baskets) (Ward et al., 2002). While the dramatic increase in marine litter in 2000 cannot, as this stage, be correlated with changes in fishing activity, there is clearly scope for detailed historical and spatial analysis of fisheries activity in the region.

In all other litter surveys of the southern coast of Australia, similar levels and types of litter have been recorded—however, unlike Anxious Bay, these surveys have generally not been repeated.

4.3. Impacts of litter on marine wildlife

Fisheries litter entanglements (and direct by-catch mortalities) represent potential threats to both, marine mammals and seabirds in the Great Australian Bight, as elsewhere in southern Australia (Gales, 1990; Pemberton et al., 1992; Copley, 1995; Marsh et al., 1995; Shaughnessy, 1999). For endangered and threatened species that have significant nearshore calving and breeding areas in the Bight, such as the southern right whale (*E. australis*) and the Australian sea lion (*N. cinerea*), fisheries entanglements pose significant threats to the recovery of these populations (Bannister et al., 1996; Gales et al., 1994). Despite the large colonies of rare Australian sea lions (*N. cinerea*) and New Zealand fur seals (*Arctocephalus forsteri*) on the offshore islands off Eyre Peninsula (Gales et al., 1994; Shaughnessy et al., 1994), there was only one record of a stranded sea lion during the beach survey and the cause of mortality was unknown. Similarly, there was no direct evidence of entanglements or fishing-related mortality in the stranded dolphins and seabirds. The low level of seal strandings however could possibly be due to the lack of haul out or breeding sites in Anxious Bay (the closest site being West Waldegrave Island), as sea lions are known to spend a considerable portion of their time either resting or traversing the waters in the immediate vicinity of colonies (Shaughnessy, 1999).

In addition to entanglements, marine debris, particularly plastics, can also have a significant impact on marine wildlife (notably seabirds and other surface-feeding animals) (see Derraik, 2002, for review) through ingestion (Furness, 1985; Ryan, 1987a,b); via regurgitation (from adult seabirds to their chicks) (Fry et al., 1987); or via the food chain (by the consumption of prey with plastics in their gut) (Kartar et al., 1976). Plastics can also affect wildlife through the absorption of polychlorinated biphenyls from ingested plastics (Ryan et al., 1988). Plastic micro-debris is more persistent in the marine environment, and consequently has the potential for a greater ecological impact on marine life than macro-debris (Derraik, 2002). Litter fragments or micro-debris (mostly plastic) was widespread in the beach sands in the foredunes at Anxious Bay, but were too small (<2 cm diameter) and numerous to be counted on these surveys.

4.4. Long distance litter

While beach litter on Anxious Bay originates predominantly from fishing and shipping activities conducted within the Great Australian Bight—exotic and long-distance litter (albeit low levels) were also recorded. One particularly interesting item was the 'message in a bottle' from Cape Town (South Africa).

The occurrence of long distance litter at Anxious Bay, from South Africa, South America and from foreign fishing and shipping vessels (i.e. Taiwanese, Greek, Japanese and South African vessels) deep in the Southern Ocean, clearly underlies the influence of the Antarctic circumpolar current on the oceanography of the Great Australian Bight. Notwithstanding, the number of items is very low, compared to similar litter surveys conducted in the northern hemisphere (Pruter, 1987), emphasising the remoteness of the region.

At a continental scale, the Leeuwin Current advects natural flotsam into the Bight region (Rochford, 1986; Cresswell, 1991; Herzfeld and Tomczak, 1997). The Leeuwin Current is strongest in April–May, when it rounds the southwestern tip of Western Australia bringing tropical flotsam into the Bight (Rochford, 1986). In this regard, dammar resins from Dipterocarp trees in Sumatra were found at Anxious Bay in 1992 (McKirdy et al., 1994). Nikars and other tropical drift seeds have not been found so far on these beach clearances, but coconuts have been reported by local people. The occurrence of a dead stranded tropical turtle at Anxious Bay in the 1996 survey, is further evidence of the influence of the Leeuwin Current in advecting natural tropical flotsam into Bight.

Continuing submarine eruptions, probably in the South Sandwich arc, are the likely source of the southern ocean pumice recorded at Anxious Bay. In this regard, the arrival of pumice in Australia (Tasmania) and New Zealand from the large submarine eruption in the South Sandwich Islands in March 1962, has been well documented (Coombs and Landis, 1966; Sutherland and Olsen, 1968). Continuing eruptions in the island arc might also be the source of later pumice recorded on sub-Antarctic islands in the southern ocean (i.e. Heard and Macquarie Island) (Dr Harry Burton, Australian Antarctic Division, personal communication). In this regard, basaltic lavas in the Kerguelen and Heard region do not have the appropriate eruptive centres, which tend to be concentrated on island arcs at the edge of tectonic plates. Geochemical signatures from trace element analyses for pumice might confirm the source of pumice at Anxious Bay, in the same way that sea-rafted from the tropics has been confirmed for the east coast of Australia (Ward and Little, 2000).

The records of tagged animals in the survey (i.e. albatross and Southern Bluefin Tuna), provides researchers with vital knowledge of the number and movements or migrations of our some of most long-distance travellers, such as seabirds, pelagic fish, and marine mammals. All of these items, including the long-distance litter, also provide interesting research and education topics for the school children involved in the program.

4.5. Litter monitoring on Australian coasts

The need for information on marine debris is essential to assessing the ecological sustainability of marine activities, such as fisheries. The occurrence of long distance litter at Anxious Bay, from South Africa, South America and from foreign fishing and shipping vessels (i.e. Taiwanese, Greek, Japanese and South African vessels) deep in the Southern Ocean, clearly indicates that ocean-based litter monitoring needs to be integrated at an international level. While litter from foreign fishing vessels and shipping continues to be recorded along Australia's coasts, there are presently no formal international management frameworks, particularly guidelines or monitoring protocols and programs to assess and manage ocean litter at the regional level. Apart from programs under CCAMLR, there are presently no international frameworks or programs for assessing ocean litter in the Southern Ocean.

Australia undertakes annual marine debris monitoring at Heard Island and Macquarie Island, as part of the CCAMLRs commitment to long-term monitoring in the Antarctic marine environment (Gregory and Ryan, 1997). Further, CCAMLR has adopted and implemented measures to monitor marine debris and to mitigate its impact on marine biota in the Convention Area. At present, CCAMLR members monitor beached marine debris at several locations in the Convention Area and long-term monitoring programs have been established by Australia, Brazil, Chile, Norway, South Africa, the UK, Uruguay and the USA. A Standard Method for Surveys of Beached Marine Debris was prepared and adopted by CCAMLR in 1993 and surveys of beached marine debris are now carried out in accordance with this standard method. Marine debris is now being systematically monitored in the Southern Ocean following the initiation of CCAMLR recording sites (see Gregory and Ryan, 1997).

In Australia, a recent Commonwealth review of fishing debris in the Australian marine environment (Jones, 1995), identified three areas for attention to assist fisheries in meeting their fisheries ecosystem management objectives for marine debris and to fulfilling Australia's international obligations under MARPOL, to reduce ship based litter: (i) a reduction of inputs of fishing debris into the ocean, (ii) collection of observer data on domestic fisheries (especially those using monofilament nets, demersal trawl nets and longlines), (iii) and improved disposal facilities in some ports. Unfortunately, the regulations of MARPOL are difficult to enforce due to Australia's long coastline and the lack of a coastguard. For these reasons, official observers on board vessels and systematic beach litter survey surveys remain some of the best tools for assessing compliance. Jones (1995) recommended that the problem of fishing litter in the southeast of Australia could be reduced

through an industry education program, improved port disposal facilities, plastic-free bait boxes and net recycling. To-date there is no national program or management framework in Australia to assess, manage and monitor fisheries-related ocean litter, and monitor compliance with MARPOL.

Ocean litter is currently not addressed under the Australian State of the Environment Reporting (Commonwealth of Australia, 1996) and no standardised methodology or indicators have been developed as part of national reporting (Ward et al., 1998). Unlike the Tasmanian and many other beach surveys, the Anxious Bay surveys have measured debris by weight rather by number of items, because much plastic is disintegrating on the beach. There is a need for standardised methodology for national ocean litter monitoring and reporting (Wace, 1995, recommendations 1 and 2).

The annual beach litter survey at Anxious Bay is Australia's longest running survey of ocean litter, testing the effectiveness of the MARPOL (Annex V) legislation in our southern temperate waters. This volunteer program utilises the expertise of marine scientists with the involvement of local schools, and more recently, residents and staff from Cavan Training Centre (a juvenile detention centre) in Adelaide. It attempts to raise community awareness of ship-based marine pollution and to monitor the type and quantity of ocean litter in the nearby Southern Ocean. There is presently no formal State and Federal Government policy commitment to ocean litter monitoring in Australia. In general, beached litter surveys around Australia are conducted on an 'ad hoc' basis, undertaken by researchers and/or community groups without any formal government commitment to undertake long-term monitoring. The annual clearances of ocean litter at Anxious Bay are an example of long-running community-based surveys that yield valuable data on marine pollution, and should attract long-term government support.

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